United States Department of Agriculture
Soil Conservation Service
Engineering Division

Technical Release No. 27
February 4, 1965

LABORATORY AND FIELD TEST PROCEDURES FOR CONTROL OF DENSITY AND MOISTURE OF COMPACTED EARTH EMBANKMENTS

The purpose of this technical release is to coordinate procedures used for controlling moisture and density of compacted earth materials in laboratory testing operations and field construction control.

The kinds and details of tests vary with kinds of soil involved.

A. Fine-Grained and Non-Gravelly Soils (less than 5% rock larger than No. 4 sieve).

All laboratory and construction control tests will be based upon the moisture-density relationships of soil processed to pass a No. 4 sieve.

Compaction requirements will call for Compaction Class A controlled to a specified degree of maximum density obtained by ASTM Test Designation D-698 or D-1557 - Methods A or B.

Design values will generally be determined by testing soil compacted to the specified percentage of maximum density obtained by the Standard (D-698) compaction test. Higher compactive efforts, e.g., Modified compaction, D-1557, may be used to determine the compacted properties of some highly plastic (CL and CH) soils. In such cases, design values will generally be determined by testing soil compacted to 90% of maximum "modified" density.

Field Compaction Control: The dry density and moisture content of the compacted fill will be determined by using density tests S-2 (Sand Cone), S-3 (Rubber Balloon), S-4 (Calibrated Cylinder), S-5 (Kerosene), and moisture tests S-10 (Oven), S-11 (Quick Dry), S-12 (Alcohol), or S-13 (Speedy Moisture Meter) given in NEH, Section 19 - Construction.

The degree of compaction of material in the fill is determined by computing the ratio of in-place embankment density to maximum density of the same material determined by moisture-density tests S-6 (Rapid Method), S-7 (ASTM D-698), or S-8 (ASTM D-1557) given in NEH, Section 19.

Results from moisture-density tests (S-6, S-7, or S-8) previously determined may be used as basis for computing degree of compaction in the fill provided (a) materials tested in the fill are essentially the same, based on standard unified soil classification field tests, as those for which moisture-density curves were

previously developed <u>and</u> (b) the moisture content of material tested in the fill is near optimum and the density value determined by compacting one mold of material at placement moisture taken from the immediate area of the in-place embankment test falls on or very near the predetermined moisture-density curve (using the same procedure for both compaction tests).

It is always advisable to develop moisture-density curves <u>on the job</u> for each kind of material excavated for use on the fill. Soil masses are too variable to expect that all material excavated from a specific borrow source will be exactly like the small sample tested in a laboratory. If the maximum density of a job curve varies significantly from that used in the design of the embankment, this fact should be brought to the attention of the design engineer immediately to be sure the material fulfills design requirements.

Many materials excavated from specific borrow sources are variable from load to load. Variations in materials may be due to stratification, irregular topography and depth, spotty and irregular areal patterns of deposition or other causes. In such cases, complete moisture-density curves should be developed as a basis for computing the degree of embankment compaction. These compaction tests should be made using soil taken from the immediate area around the in-place embankment density test excavation. Three or more individual compaction test molds will generally be required to define the maximum density-optimum moisture values for each sample. A new portion of the sample may be used for determining each point on the moisture-density curve if this is more convenient than re-using the same portion for each point as prescribed in Tests S-7 and S-8.

There will undoubtedly be many situations where variations in borrow material that appear to be significant will have little effect upon maximum density-optimum moisture relationships and moisture-density curves developed for a number of in-place embankment density test sites will be essentially the same. In such cases, these previously determined moisture-density curves may serve as a basis for using "one-point" moisture-density tests previously discussed for use in uniform soils.

B. <u>Coarse-Grained Soils - Group I</u>. Gravelly and stony soils (more than 5% larger than No. 4 sieve) with hard, durable rock.

1. <u>Sub-Group IA</u> -- Soils with more than 65% passing No. 4 sieve (< 35% rock).

   Design and construction control tests will be based upon moisture-density relationships of the fill matrix (minus No. 4 or 3/4" fraction). The fill matrix is defined as that fraction of the soil-rock mixture having a maximum size equal to that used in the compaction test method.

Compaction requirements will call for Compaction Class A controlled to a specified degree of maximum density obtained by performing ASTM Test Designation D-698 or D-1557.

Design values will generally be determined by testing the fill matrix compacted to 95% of maximum Standard density (D-698). When it is desirable to obtain different engineering properties, higher compactive efforts may be used.

Field Compaction Control: The in-place density and moisture content of the compacted fill will generally be determined according to Test S-2, Alternate A, NEH, Section 19.

The moist weight and volume of the total sample will be determined, after which the total sample will be screened or washed through a No. 4 or 3/4" sieve, depending on the method used. The moisture content should be determined on a representative sample of the fill matrix. The moist weight and volume of the rock is determined. The volume of the rock should be measured by displacement in a siphon can or a graduated cylinder. Details on separating and measuring the volume of the rock are covered in Appendix I. The weight of moist rock should be deducted from the total moist weight of sample and the volume of rock deducted from the total volume of sample, after which the approximate moist weight, volume, and moist densitv of the fill matrix can be computed. The dry density of the fill matrix is then computed, using the moist density and moisture content values.

The degree of compaction will be computed as the ratio of in-place dry density to maximum dry density obtained by performing specified tests on the fill matrix taken from and immediately around the in-place density test excavation. As discussed under Fine-Grained Soils, Part A, if the fill matrix of the soils from a specific borrow source is unirorm in gradation and composition, comparison of results from one compacted mold or specimen with a complete compaction curve previously developed may be adequate to define the maximum compacted density for that particular test.

2. Sub-Group IB -- Gravelly and stony soils with 65% to 35% passing No. 4 sieve (35% to 65% hard, durable rock).

   a. Laboratory tests and design values.
   Tests on the minus 3/4-inch fraction of the soil-rock material will generally be used as the basis for design when all borrow materials have about the same gradation characteristics in the fraction passing the 3/4-inch sieve and the total material contains less than 35% rock larger than 3/4-inch size.

Laboratory tests will generally be performed on specimens of the minus 3/4-inch fraction compacted to 95% of maximum density obtained by ASTM D-698, Method C or D. When it becomes desirable to obtain different engineering properties, higher compactive effort may be used.

Mass density may be used as the basis for degin tests when proposed borrow materials are quite variable in the gradation of the minus 3/4-inch fraction, or have more than 35% larger than 3/4-inch. In such cases, laboratory tests will be performed on materials passing the 1-inch or 3-inch sieve compacted to an arbitrary base density of the mass with varying amounts of rock. The base density of the mass will generally be established as 95% of maximum density of the minus No. 4 fraction compacted by ASTM D-698 and adjusted for 40% rock.

When considerable variation in the rock content of borrow materials is indicated by investigations, the design should be based on the characteristics of the material in the least desirable condition of rock content. Specifications can then call for random fill from the specified borrow sources.

b. Field compaction control.

Care in selecting and judging a representative site for in-place density tests is very important with these types of materials. Details on this subject are covered in Appendix I.

When Class A compaction is specified, in-place density tests will be made in accordance with Test S-2 (ASTM D-1556, Sand Cone), NEH, Section 19, or by using plastic lining and water to measure the volume of the test hole as described in Appendix I. The moist weight and volume of the total sample will be determined, after which the total sample will be screened through a 3/4-inch sieve. The moisture content should be determined on a representative sample of the minus 3/4-inch fraction. The moist weight and volume of the rock larger than 3/4-inch will be determined and subtracted from values for the total sample. The preferred method of determining the volume of plus 3/4-inch rock is to measure displacement in a siphon can or graduated cylinder. This method may not be practical when the plus 3/4-inch rock exceeds 3 inches to 4 inches in diameter. When the rock is uniform in composition, the volume of rock may be computed by dividing the dry weight of rock by the bulk density of the rock, as given in laboratory reports or determined by Test S-15, NEH, Section 19.

The maximum density of the minus 3/4-inch fraction should be determined by Test S-7, NEH, Section 19 (ASTM Test D-698 or D-1557, Method D) on material taken from and immediately around the in-place density test excavation.

When compaction of the fill is controlled by the specification of the type of equipment and the number of passes per lift, sufficient density tests should be made to insure that the specified compaction methods obtain the desired results. In-place density tests will be performed by the same procedures described for control of Class A compaction. Control will usually be based on determination of the density of the fill matrix (minus 3/4-inch fraction). Determination of mass density may suffice for checking the condition of random fill from selected borrow sources.

3. Sub-Group IC -- Stony and rocky soils with less than 35% passing No. 4 sieve (> 65% hard, durable rock larger than No. 4 sieve).

   Type of equipment and number of passes per lift will be specified for control of compaction of these materials. Occasional in-place density tests may be required to correlate equipment performance in various materials. Such tests will require determinations of mass density.

C. Coarse-Grained Soils - Group II. Rocky and stony materials with moderately durable rock (hard shale, siltstone, sandstone, schist, etc.).

Excavation and compacting processes, including moisture-density tests (D-698 or D-1557) change the gradation of these materials. The rock fraction is hard enough, however, to allow physical sieving of various sized fractions without further breakdown.

Insofar as possible, laboratory testing, design values and compaction control of these materials should be based on characteristics of samples taken from test fills. The breakdown characteristics should certainly be known prior to testing and design for all moderate to high hazard or important structures involving use of these materials.

Predictions of breakdown will be made on the basis of special laboratory tests and correlation studies when data from constructed embankments or test fills are not available. (Figure 1 and Table 1.)

1. Sub-Group IIA -- 65% or more passing No. 4 sieve after compaction.

   Laboratory tests and design values.
   Design values will be determined by testing the minus No. 4 fraction when breakdown results in compacted material with less than 35% rock (plus No. 4) or when this high degree of breakdown is required to secure adequate strength, impermeability or other engineering properties.

Laboratory tests will be conducted on samples processed to pass a No. 4 sieve with all particle sizes represented in the mixture. Test specimens will generally be compacted to 95% of maximum density obtained by Test ASTM D-698, Method A, or 90% of maximum density obtained by Test D-1557, Method A.

Compaction requirements will generally call for Compaction Class A controlled to a specified degree of maximum density obtained by specified test method. They may also call for compacted material to have a certain breakdown as: 65% or more passing No. 4 sieve.

Field compaction control.
In-place density will be determined using Tests S-2, S-3, S-4, or S-5, NEH, Section 19, with Test S-2 generally preferred. The test sample should be separated on a No. 4 sieve. Material larger than No. 4 sieve should be cleaned as well as possible without washing (see Appendix I). The moist weight and volume of material larger than the No. 4 sieve will be determined and subtracted from the total moist weight and volume of the test sample.

Volume measurements of the rock fraction by water displacement will require soaking the rock to saturation prior to measurement if it is not already near saturation.

Volume measurements of rocks that disintegrate when soaked in water should be made by (a) substituting kerosene or diesel fuel for water as a displacement liquid in Test S-5, NEH, Section 19, or (b) determining the moist bulk density of several larger pieces or rock representing the entire rock fraction by Test S-15, Method B, NEH, Section 19.

Additional instructions for measuring the volume of moderately durable rocks are included in Appendix I.

When moist bulk density of individual rocks is used to compute the total volume of rock, it must be determined that the moisture contents are comparable for the rock in the test sample and rock used for the bulk density tests. In such cases, the total volume of rock in the sample would be computed as:
Moist weight of rock divided by moist bulk density of rock. If various kinds of rock occur in the test sample or if the moisture content of the rocks is variable, all rocks in the test sample and in the bulk density determination should be dried and the bulk density computed on the basis of dry weights.

Maximum density values to be used in computing the degree of embankment compaction should be determined by performing the specified Test D-698 or D-1557 (Method A or B) on material passing a No. 4 sieve collected from and immediately around the in-place density excavation.

2. Sub-Group IIB -- 65-35% passing No. 4 sieve after compaction (35-65% moderately durable rock larger than No. 4 sieve after compaction).

Laboratory tests, design values and compaction control should be based on characteristics of materials compacted in test fills whenever possible. Proposed use of these materials in critical sections of any structure will require test fill information prior to testing and design.

The long-time weathering and stability characteristics must be considered in establishing design values and placement recommendations for all materials containing more than 35% non-durable rock.

When Class A compaction is specified, laboratory tests and construction control will be based upon mass density.

Laboratory tests and design values.
Laboratory tests and design values will be based upon maximum density of the minus No. 4 fraction adjusted for 40% plus No. 4 with varying percentages of rock. As an example, shear and permeability tests might be performed on samples of the mass passing 1-inch or 3-inch sieves and graded according to laboratory breakdown tests (Figure 1). All test specimens would be compacted to a specified base density equal to specified percentage of maximum modified (D-1557) density of the minus No. 4 fraction adjusted for 40% rock. Different amounts of rock would be added to each set of test specimens. For example: (a) The maximum modified density of the minus No. 4 fraction of a shale sample might be 105 p.c.f., (b) 90% of maximum modified γ_d = 95 p.c.f., (c) assuming a bulk density of the shale at 140 p.c.f., the adjusted γ_d of the mass with 40% rock would be 108 p.c.f, and (d) all test specimens would be compacted to a mass density of 108 p.c.f. with one set containing 35%, one set 50%, and another set 65% rock of uniform gradation between the No. 4 size and maximum size to be tested.

Field compaction control.
In-place density will generally be determined using Test S-2, NEH, Section 19, or the plastic liner method. Instructions for separating and measuring the volume of rock when size separations are required are given in Appendix I.

Compaction requirements may call for minimum mass density regardless of amount of rock or they may call for specific mass densities for varying rock contents. In the latter case, it would be necessary to determine the percentage by dry weight of plus No. 4 material for each in-place density test.

Moisture tests on these materials may require special methods discussed in Appendix I.

3. Sub-Group IIC -- Less than 35% passing No. 4 sieve after compaction (>65% moderately durable rock).

   Laboratory tests and design values.
   Laboratory tests will not generally be performed on these materials. Design values will be based on results of tests on similar materials adjusted for rock contents greater than 65%, on field evaluation of actual performance in constructed fills, and on published data for large-scale field and laboratory tests.

   The long-time weathering and durability characteristics of these materials are extremely important in establishing design and placement recommendations.

   Field compaction control.
   Compaction control tests will not generally be performed on these materials and compaction requirements will be based on specification of method of placement.

D. Group III. Gravelly and stony soils containing soft, non-durable rock.

The rock fractions of these materials are so soft and break down so easily that it is impossible to make a physical separation of various sizes.

Laboratory tests and construction control will be based on mass density. It is important, however, that information be submitted with laboratory samples stating that size separations will not be feasible for construction control of these materials. Unless the testing facility is informed that such separations are not possible for construction control, laboratory tests and design values might be based erroneously on size separations that cannot be made on the job.

Laboratory tests and design values.
Design values for these materials will involve a series of laboratory tests based on moisture-density relationships of material processed to pass No. 4 sieve. Individual test samples will be synthesized by the addition of varying amounts (20% to 40%) of plus No. 4 material.

Field compaction control.
Compaction requirements will call for a minimum mass density. In-place density will be determined by Tests S-2, S-3, S-4, or S-5, NEH, Section 19.

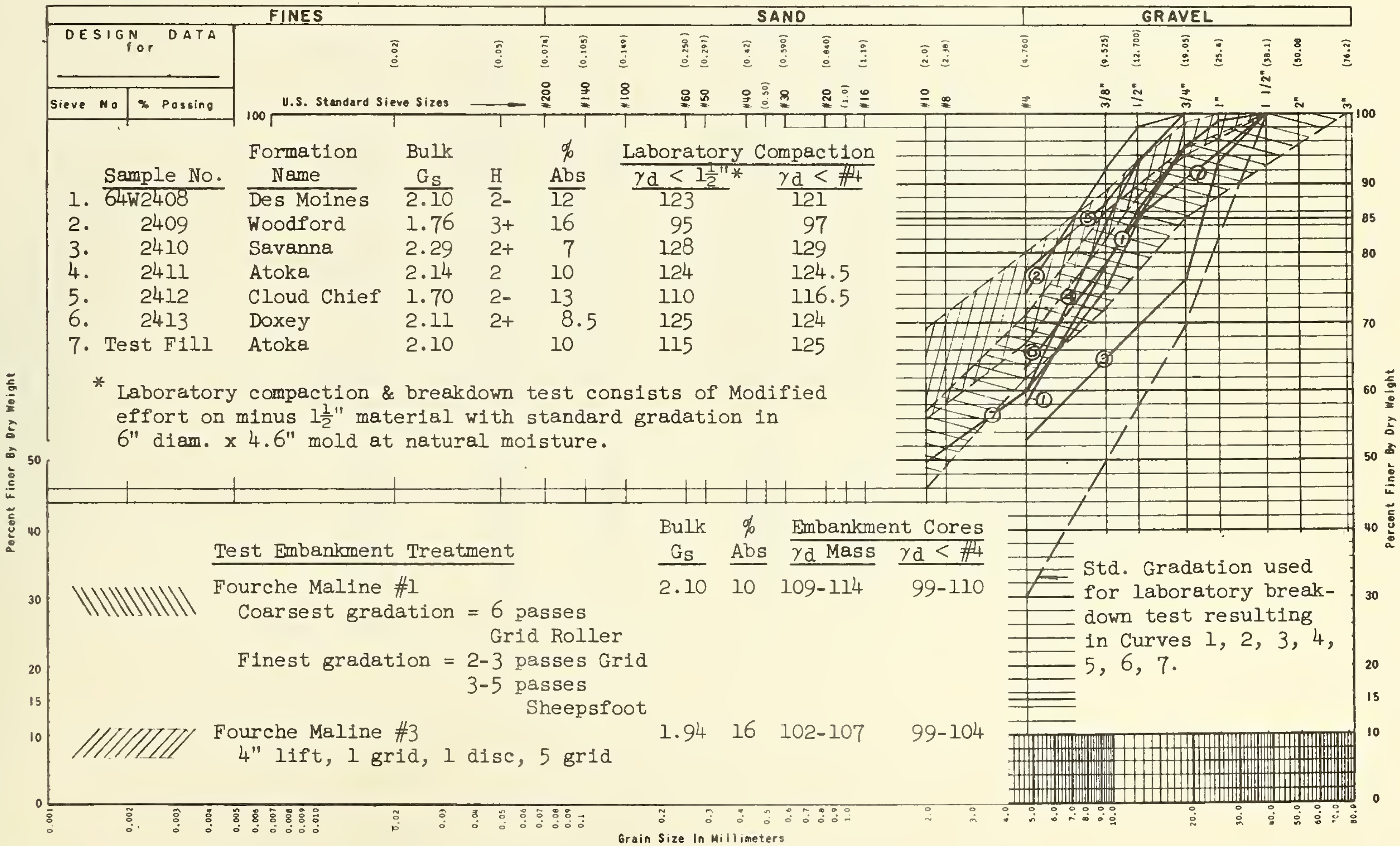
OKLAHOMA SHALES: COMPARISON OF LABORATORY BREAKDOWN WITH FOURCHE MALINE TEST FILL CORES

Form SCS- 353

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

GRAIN SIZE DISTRIBUTION GRAPH

Project ______________ Location ______________



	Sample No.	Formation Name	Bulk G_s	H	% Abs	Laboratory Compaction $\gamma_d < 1\frac{1}{2}$"*	$\gamma_d <$ #4
1.	64W2408	Des Moines	2.10	2-	12	123	121
2.	2409	Woodford	1.76	3+	16	95	97
3.	2410	Savanna	2.29	2+	7	128	129
4.	2411	Atoka	2.14	2	10	124	124.5
5.	2412	Cloud Chief	1.70	2-	13	110	116.5
6.	2413	Doxey	2.11	2+	8.5	125	124
7.	Test Fill	Atoka	2.10		10	115	125

* Laboratory compaction & breakdown test consists of Modified effort on minus $1\frac{1}{2}$" material with standard gradation in 6" diam. x 4.6" mold at natural moisture.

Test Embankment Treatment	Bulk G_s	% Abs	Embankment Cores γ_d Mass	$\gamma_d <$ #4
Fourche Maline #1 Coarsest gradation = 6 passes Grid Roller Finest gradation = 2-3 passes Grid 3-5 passes Sheepsfoot	2.10	10	109-114	99-110
Fourche Maline #3 4" lift, 1 grid, 1 disc, 5 grid	1.94	16	102-107	99-104

Std. Gradation used for laboratory breakdown test resulting in Curves 1, 2, 3, 4, 5, 6, 7.

Figure No. 1

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

TABLE 1 - CHARACTERISTICS OF OKLAHOMA SHALES USED FOR COMPARISON OF LABORATORY BREAKDOWN TEST RESULTS AND TEST FILL BREAKDOWN RESULTS

Sample No. 64W	Site	Geologic Formation	Hard- ness	Free Swell %	Slaking (1 hour)	Atterberg Limits (- #40) LL	Atterberg Limits (- #40) PI	Class	Salt	Disp	Fines Gs	Bulk Density of Rock γd pcf	Bulk Density of Rock w %	COMPACTION Mod. (- #4) γd	COMPACTION Mod. (- #4) wo %	One Point at Mod. Effort - 6" Mold: Test.	Gradation - (Before)/(After) < #4	Gradation - (Before)/(After) < 3/4"	Gradation - (Before)/(After) < 1-1/2"	γd	w %	Project Engrs. Evaluation of No. 4 Separation After Compaction on Fill
2408	Upper Clear Boggy #24	Des Moines (Mid-Penn) Gray Mod. hard Breaks easy w/fingers	2-	30	Severe	43	22				2.74	130.0	10.0	121.0	12.5	(a) (b) (c)	32/58 32/60 0/61	69/95 97/95 0/97	100/100 100/100 100/100	123.3 122.8 132.2	12.5 12.2 11.0	Impossible
2409	Upper Clear Boggy #33	Woodford (Penn) Hard, flat platy shale Brittle	3+	20	None	43	11				2.50	110.0	11.3	97.0	21.0	(a) (b) (c)	32/74 32/74 0/57	69/100 69/100 C/95	100/100 100/100 100/100	94.6 95.1 102.0	15.7 15.1 11.7	Possible
2410	Fourche Maline #4	Savanna Hard, soapy shale Very difficult to break with fingers	2+	20	Slight	34	13				2.76	143.0	6.6	129.0	10.5	(a) (b) (c)	32/53 32/52 0/39	69/85 69/87 0/74	100/100 100/100 100/100	127.5 128.0 134.3	7.2 7.3 6.5	Possible
2411	Sallisaw #11	Atoka Hard, slatey Difficult to break w/fingers	2	30	None	37	13				2.83	134.0	9.8	124.5	12.0	(a) (b) (c)	32/59 32/61 0/56	69/99 69/98 0/99	100/100 100/100 100/100	124.1 122.9 127.1	10.1 10.2 9.4	Difficult
2412	Boggy #28	Cloud Chief (Perm) Red-brown soft siltstone Breaks easy w/fingers	2-	0	Severe	36	15				2.72	106.0	12.7	116.5	13.5	(a) (b) (c)	32/77 32/71 0/82	69/100 69/99 0/95	100/100 100/100 100/100	110.8 109.6 119.6	12.6 13.7 9.1	Impossible
2413	Boggy #13	Doxey (Perm) Red-br. hard siltstone Very difficult to break	2+	20	Slight	31	9				2.75	132.0	7.6	124.0	12.5	(a) (b) (c)	32/63 32/62 0/54	69/95 69/95 0/92	100/100 100/100 100/100	125.3 124.4 132.1	8.6 8.6 7.8	Difficult

Comp. Test (a) Natural Moisture; Standard Gradation, 100% < 1-1/2", 69% < 3/4", 32% < #4.
Comp. Test (b) Test (a) Sample with Absorbed Water.
Comp. Test (c) Special Gradation; 100% < 1-1/2", 0% < 3/4".

APPENDIX I[1]

Details on Construction Control Tests for Rocky Soils in Compacted Earth Fills

Methods and equipment required for moisture-density (compaction) control tests in rocky soils vary from those ordinarily used for fine-grained soils.

Such factors as the selection and preparation of a representative test site, the dimensions of the control test hole, the type and size of equipment used to measure the volume of the test hole, sample sizes needed for moisture determinations are all affected by the amount of rock, the kind of rock (durable or non-durable), and the size of rock in the compacted embankment to be tested.

I. Test Site Selection.

The site selected for an in-place density test in rocky soils should represent average soil and rock conditions for a particular zone or lift of fill or borrow source.

A site containing occasional rocks larger than normally encountered would not be representative. Randomly occurring rocks two to three times larger than the maximum size of the major portion of embankment material being tested should generally be considered as non-representative. This is particularly true when dealing with many of the fine gravelly tills and alluviums containing less than 35% rock with occasional cobbles. For compacted materials with mass densities of 110 to 125 p.c.f. and rock densities of 120 to 140 p.c.f., one 5-inch diameter rock would be equivalent to about 35% of the total sample from a test hole 6 inches in diameter x 8 inches deep. If all other rock in the sample is 2 inches or less in diameter, a 5-inch diameter rock is obviously not representative of the rock fraction. Similarly, a 2-inch rock may produce misleading results in a density test sample of material containing up to 65% rock which otherwise passes the 1/2-inch sieve.

When random oversize rocks are encountered in a test, a new site should be selected or the weight and volume of the oversize rock deducted from the total weight and volume of the test sample. Proper notations should be entered in the density test records when adjustments in weight and volume are made for oversize rock.

1/ Appendix to Technical Release No. 27, titled "Laboratory and Field Test Procedures for Control of Density and Moisture of Compacted Earth Embankments."

The amount of rock in a density test sample should represent average conditions. A site containing 5% to 10% rock would hardly be representative when most of the soil being used contains 25% to 35% rock.

II. Test Hole Volume Measurements.

The size of test hole and the type of equipment used to measure the volume of material removed vary with the amount of rock and the maximum size of rock.

Table A-I, attached, shows recommended minimum volumes and dimensions of in-place density test holes for varying sizes of rocky materials. Test hole dimensions include top width, bottom width, and depth. Bottom width dimensions are included since it is difficult to excavate test holes with vertical side walls in rocky soils.

Methods for measuring test hole volumes are identified in Table A-I. The Sand Cone Method (NEH, Section 19 - Test S-2) using ccnes 6.5 inches and 12 inches in diameter generally works well for materials with maximum size rocks up to 4 inches in diameter.

For very rocky materials with particle sizes larger than 4 inches in diameter, the pliable liner-water volume method is recommended. This method involves fitting a thin rubber or polyethylene sheet liner into the test hole and measuring the volume of water required to fill the lined hole. Plastic drop sheets classified as No. 4 and 0.004 gauge available in most paint and hardware stores work well for this test. The plastic sheets should be thin enough to conform to surface irregularities in the test hole, yet sturdy enough to resist puncture by sharp rocks.

A. Test Site Preparation and Measurement of Surface Irregularities.

Any in-place density test site should be as level and smooth as practicable. Surface irregularities generally exist, however, when testing rocky soils.

1. Sand Cone Method

In using a sand cone for density tests, a base plate may or may not be used. In either case, the tare weight of sand necessary to fill the cone is generally determined for each calibrated lot of sand and then used as a standard weight in subsequent tests. When surface irregularities exist at the location of the in-place density test, the standard weight of sand to fill the cone, as previously determined on a plane surface, will not be applicable. Using a standard correction for amount of sand to fill the cone will result in a volume less than true

volume of material removed (higher density than true) when rocks extend above the surface of the plane to be excavated. A volume greater than true volume of material removed (lower density than true) will result when holes and indentations occur on the surface of the plane to be excavated or when the base plate is not flush with the surface and sand moves into any annular space between base plate and test surface.

Whenever the surface cannot be prepared in a level plane, a test should be run on the test site before the hole is excavated to determine the amount of sand necessary to fill the cone and surface irregularities - ASTM D-1556, Note 7.

2. Plastic Liner Method

The same potential error in volume measurements on irregular surfaces exists when using the plastic liner and water method.

The following procedure is recommended when the surface of the test location cannot be prepared in a level plane.

a. A template made of metal (preferred) or wood, square or round, and varying in size from 24 inches to 72 inches x 2 inches to 6 inches high should be firmly seated over the test location in as level position as possible. Rocks immediately under the edges of the template should be removed without disturbing the surrounding soil and discarded from the test.

b. Fit the plastic liner inside the template, taking care to eliminate all folds in the plastic, to fit it snugly into the corners of a square template and to line any cavities along the edge of the template resulting from removal of rocks in the seating process.

c. Measure and record the amount of water required to fill the template to a point of overflow or some arbitrary level measured by hook gauge or other accurate means. It is generally easier to weigh the water involved than measure volumetrically.

d. Remove the water and plastic liner and proceed with the test. At least part of the water should be removed before attempting to lift out the liner.

B. Test Hole Excavation.

Care should be exercised in excavating and preparing the hole for in-place density measurements.

The top dimension of the hole should be the same dimension as the hole in the sand cone base plate or liner template.

The sides of the hole should be as smooth as possible. Rocks and stones protruding from the sides may prevent the sand or waterfilled plastic from completely filling all voids under and around the rocks. This is particularly true when the stones are flat or angular and oriented at right angles or obliquely downward to the vertical axis of the hole. In such cases, it is generally better to remove the stone from the side of the hole than to leave it in place. When a stone is removed from the side of the hole, the resultant cavity should be enlarged and flared to allow free and full occupancy by sand or liner.

The bottom of the hole should be dished or cupped as much as possible.

C. Volume Measurements.

Extreme care should be exercised in making and recording all measurements of weight and volume. Small errors in any measurement are accumulative and become significant when converted to units of pounds per cubic foot.

The procedure for measuring the volume of material removed from the density test excavation with sand cone is well covered in the Construction Handbook and in ASTM D-1556.

The procedure for the plastic liner method is as follows:

1. Seat template and liner on surface to be tested. If surface is not smooth and level, determine amount of water to fill the template to overflowing or to a predetermined level on the template.

2. Excavate hole within confines of the template. Save and weigh material removed from the excavation.

3. Fit the plastic liner into the hole as snugly and evenly as possible. This can best be done by working the liner against the sides of the hole as it is filled with water.

4. Determine amount of water necessary to fill the hole and template to overflowing or to the same level as used to determine initial tare for surface irregularities (Step 1). Water measurements will generally be made in pounds (to the nearest 0.01 lb.), grams or cubic centimeters. Check the hole to be sure the plastic did not leak after emptying and removing the liner. If leaks have occurred, the volume measurement must be repeated.

5. The volume of material removed from the test hole will be equivalent to the total volume of water used to fill the hole and template less the volume used to fill the template on the surface of the ground (tare) as:

Volume in cu. ft. = (Total pounds water - tare pounds water) x 0.01603

= (Total grams or c.c. water - tare grams or c.c. water) x 0.0000353

Other conversion factors which may be useful are:

1 gallon water @ 62° F. = 8.337 lbs.
= 0.13368 cu. ft.
= 3785.4 cu. centimeters

1 pound (avoirdupois) water = 0.01603 cu. ft.
=453.6 grams or cu. cents.

1 cu. cent. (c.c.) = 1 gram water = 0.0000353 cu. ft.

1 cu. ft. water = 62.4 lbs.

III. Screening and Separating Coarse and Fine Fractions when it is Necessary to Determine the Amount of Rock Larger than a No. 4 or a 3/4-inch Sieve.

Methods used to separate the fine and coarse fractions will vary with the nature of the rock.

A. Hard Rock with Low Absorption (< 5%) Capacity.

When all rock in a sample has low absorption capacity, size separations may be made by washing the entire sample on the specified sized sieve (No. 4, 3/4-inch, etc.).

Representative samples of the finer fraction should be collected for moisture determinations before the washing process.

Absorption capacities of several samples of rock should be determined prior to actual testing operations to be sure that low absorption materials are involved. Absorption capacity may be determined in the following manner:

1. Soak rock specimens in clear water for at least 24 hours.

2. Remove specimen from water and remove all surface water by blotting and patting with absorbent paper.

3. Weigh saturated, surface dry specimens.

4. Oven dry specimens to constant weight. This may require 24 hours or longer.

5. Compute % absorption as:

$$\frac{\text{Net weight - dry weight}}{\text{Dry weight}} \times 100$$

B. Rock with Moderate to High (> 5%) Absorption Capacity (Some Hard Rock, Shale, Sandstone, Chalk, etc.) and Mixtures of Rock with Variable Absorption Capacities.

When these materials form the rock fraction of samples to be separated on the No. 4 or 3/4-inch sieve, the sample should <u>not be washed</u> through the separating sieve. Absorption of water by the rock during the washing process results in erroneous values for moist weight of rock.

The following methods are recommended:

1. <u>Materials with Low Plasticity Fines</u> (SW, SP, GW, GP, SM, GM)

   a. Determine moist weight of the total sample. Extract a representative sample of the finer fraction (minus No. 4 or minus 3/4-inch) for moisture determination. This may require preliminary screening of a portion of the sample before processing the entire sample.

   b. Sieve the total sample on the specified sieve (No. 4 or 3/4-inch) brushing and rubbing as much soil from each rock as possible.

   c. Determine the moist weight of the brushed rock.

   d. Determine the volume of brushed rock by measuring the displacement in a siphon can or graduated cylinder as described in a succeeding section.

   e. Compute the moist weight and volume of the finer fraction (minus No. 4 or minus 3/4-inch) by subtracting the moist weight of rock from the total moist weight of sample and the volume of rock from the total volume of the sample.

   f. Determine the oven dry weight of the rock if percent of rock by weight is required.

2. Materials with Plastic Fines (SC, GC).

When it is impossible to clean the rock by rubbing and brushing, the procedure should be as follows:

a. Determine moist weight of the total sample.

b. Extract a representative sample of the finer fraction for moisture determination.

c. Screen the entire sample on the prescribed sieve, rubbing and brushing as much soil as possible from the rocks.

d. Determine the moist weight of the brushed rock (plus adhering soil).

e. Wash the rock as clean as possible.

f. Determine the weight of washed rock.

g. Measure the volume of washed rock.

h. Compute the weight of moist soil adhering to the rock = [(d) - (f)]. Add this weight to the moist weight of fine fraction separated on the sieve in step (c), thus giving the total moist weight of fine fraction = [(a) - (d) + [(d) - (f)].

i. Determine the dry weight of rock if the percentage of rock by weight is required.

Note: When large samples (12-inch sand cone or plastic liner test) are involved, it may be easier to perform the sieving operations after drying the entire sample. In such cases, a representative sample of the finer fraction should be extracted for moisture determination before drying the remainder of the material.

IV. Volume Measurement of the Rock Fraction.

The following methods are recommended for measuring the volume of any portion of the rock fraction (larger than the No. 4 sieve, larger than 3/4-inch, etc.). It should be noted that rocks with moderate to high absorption (>5%) should be saturated before volume measurements by liquid displacement are made.

A. Siphon Can or Other Overflow Volumeasure.

This method involves a direct measurement of the volume of liquid displaced through an overflow pipe when a sample is completely immersed in the measuring device.

Figure A-I-a illustrates two types of siphon cans used for displacement measurements.

The Type I device has the outlet of the siphon tube at a lower elevation than the inlet. The siphon tube drains completely at the end of each measurement and must be re-primed for each test. When the volume of specimen to be measured is not sufficient to activate the siphon, non-absorbent articles of known volume can be introduced with the specimen. Be sure to subtract the known volume from the total volume displaced for net volume of specimen being measured.

The Type II device has the outlet end of the siphon tube at a higher elevation than the inlet end. The siphon tube retains its "prime" and does not drain out at the end of each measurement. When operating properly, this type of siphon can is very sensitive and is activated as soon as any object is inserted for measurement.

Care should be exercised in making the Type I device to be sure that (a) the end of the siphon tube placed inside the can is cut square and placed in a plane parallel with the bottom of the can, and (b) the inlet end of the siphon tube is reamed and filed to a sharp edge. Correct positioning and conditioning of the inlet end of the siphon tube is less critical for the Type II can but the outlet end should be reamed and filed for this type. Small diameter tubing ($<$ 3/8 inch i.d.) should be used for the Type II can since proper operation depends on retaining the "prime" in the siphon tube. Larger diameter tubing can be used for the Type I can. The curved section of the siphon tube for both types of can should be round with essentially the same diameter as the remainder of the tube. The baffle around the outlet of the siphon tube is particularly helpful in dampening the water turbulence caused by immersion of the specimen in the Type I can.

Siphon cans should be placed in a level position on a solid base when used for volume measurements. The action and accuracy of the device should be checked several times before use by measuring the displacement from a non-absorbent article of known volume.

The siphon can should always be filled above the siphon tube and allowed to drain before volume measurements are made.

Outlet tubes other than a siphon tube can be used to measure displaced overflow. Straight outlet tubes do have some disadvantages in that the last of the overflow may dribble out for several seconds (flow through a properly constructed siphon will stop instantly when water level in the can reaches that of the siphon inlet) and the lip of water formed by surface tension at the inlet of the tube may vary from test to test.

B. Direct Reading Volume Measurements.

The volume of liquid displaced by rock specimen can be determined by recording the water level in a cylinder or other container before and after immersing the specimen. Direct readings in cubic centimeters will be obtained by using a graduated cylinder.

Displaced volume can be measured in any container by marking the container, first, at the initial water level without specimen and, secondly, after submerging the specimen and then measuring or weighing the amount of liquid required to fill the container between the two marks. Figure A-I-b shows one method of volume measurement in an ungraduated container.

C. Volume measurements of moderately durable (Group II) rocks that disintegrate when soaked in water can be made using the siphon can or cylinder method with kerosene or diesel fuel instead of water as the displacement liquid.

D. Volume measurements of rocks or other materials (soil clods) that disintegrate when immersed in water can be made by waxing the specimen and then measuring water displacement in a siphon can or graduated cylinder as follows:

1. Clean and brush all soil and loose particles from the specimen.

2. Determine weight of each specimen (generally in grams).

3. Waterproof each specimen by carefully coating with melted wax.

   Note: Waterproof fish line or ladies' nylon hair nets may be used to make cradles for immersing the specimens in wax. High melting point wax (mixture of bees' wax and paraffin) provide a more uniform coating than ordinary paraffin. The temperature of the melted wax should be just above the melting point when the specimen is immersed. If the wax is too hot, it readily penetrates into the pores of the specimen. Two or more immersions in wax may be required to completely waterproof the specimens.

4. Weigh each waxed specimen (generally in grams).

5. Determine the volume of each waxed specimen (generally in cubic centimeters).

6. Strip the wax from each specimen and determine the moisture content.

7. Determine the specific gravity of the wax used to waterproof the specimens. This may be done by molding or trimming specimens of the wax into easily measured forms, weighing the specimens and accurately measuring the dimensions of the specimens. It may also be done by measuring the water displaced by a known weight of wax. Submerging the wax specimen for displacement measurements may be done by weighting the specimen with an impervious article of known volume.

8. Compute the volume of wax coating the specimen as: weight of wax divided by specific gravity of wax.

$$\text{Vol. wax} = \frac{\text{Wt. of waxed specimen (4) - wt. of unwaxed spec. (2)}}{G_s \text{ of wax}}$$

9. Compute the volume of test specimen as:

   Vol. of rock = Total volume of waxed specimen (5) - vol. of wax (7)

10. Form SCS-543, NEH, Section 19, may be used to record data for this test.

V. Moisture Determinations.

ASTM D-1556 and NEH, Section 19, provide the following guides for minimum amounts of material required for moisture determinations:

Max. Size Particles in Total Sample	Sample Required for Moisture Grams
1/2"	250
1"	500
2"	1000

Large samples of material (50 lbs. or more) are excavated for in-place density tests on embankments with rock larger than 2 inches. Selecting a representative sample for moisture determinations on such materials is no problem if density control is based on the minus No. 4 or the minus 3/4-inch fractions. The sample is separated on the specified sieve and moisture content determined on a portion of the finer material. The moisture content of the rock larger than the density control fraction is not required when volume of oversize rock is measured.

However, selecting a portion of the total sample that will represent the moisture content of the mass is very difficult when these large samples are involved. This is particularly true when

materials contain rock of variable composition and moisture absorption characteristics.

The following alternate procedures and precautions are recommended for moisture determinations of the mass on materials with more than 35% rock with maximum sizes larger than 2 inches.

A. Drying the entire sample taken from the test excavation is the preferred method for moisture determinations. Type and size of drying equipment and time involved for testing limit the practicability of this method.

B. When drying the entire sample is not practical, the sample should be separated at some arbitrary size and moisture determined for a portion of the finer fraction and for a portion or the entire coarser fraction. The problem in trying to represent the moisture content of the mass by drying a portion of the total mass arises from the difficulty in splitting out a small sample that truly represents the gradation of the total sample, especially when rock sizes range from 1/4 inch up to 4 inches to 6 inches or larger. A better representation of the smaller sizes can be made by separating the sample on a 1-inch or 2-inch sieve and determining the moisture content of 500 to 1000 grams of this fraction. If the rock in the coarser fraction is uniform in composition and hardness, a portion of the coarse fraction could be used for moisture determinations. The entire coarse fraction should be dried when different kinds of rock are present in the sample.

C. More than the normal length of time will be required to dry coarse fractions with hard rocks 1 inch or larger in size and any coarse fractions containing porous shale, chalk, sandstone and the like.

VI. Example Computations.

The following simplified examples will illustrate computations of in-place density and moisture.

A. Embankment material has 35% to 50% rock (plus No. 4) with maximum size of 4 inches. Rock consists of mixed quartzite, conglomerate and hard sandstone. Specifications call for compaction control on minus 3/4-inch fraction.

Volume Determination - 12-inch sand cone

(1) Wt. of sand to fill cone (in place) = 5.0 lbs.

(2) Wt. of sand to fill hole + cone = 45.0 lbs.

(3) Net wt. of sand for volume measurement= (2)-(1) = 40 lbs.

(4) Bulk density of test sand = 100 lbs./cu. ft.

(5) Volume of test hole = (3) ÷ (4) = 0.40 cu. ft.

Moisture-Density Determinations

(6) Total weight moist material = 60.00 lbs.

(7) Moist wt. of +3/4" fraction = 15.00 lbs.

(8) Volume of +3/4" fraction = 0.10 cu. ft. (measured)

(9) Volume of -3/4" fraction = (5) - (8) = 0.30 cu. ft.

(10) Moist wt. of -3/4" fraction = (6) - (7) = 45.0 lbs.

(11) % Moisture of -3/4" from 500 gr.sample = 15%

(12) Dry wt. of -3/4" fraction =

$$\left[(10) \div \left(1 + \frac{(11)}{100}\right)\right] = 39.13 \text{ lbs.}$$

(13) γ_d of -3/4" fraction = (12) ÷ (9) = 130.4 lbs./ft.^{3}

Note: Moisture content and dry weight of +3/4" fraction not required as specification based on -3/4" and volume of +3/4" measured.

B. Same embankment and material as Example "A" but specifications call for compaction control on mass.

Volume Determination

1, 2, 3, 4, 5 - Same as Example "A"; Volume of test hole = 0.40 cu. ft.

Moisture-Density Determinations

(6) Total moist weight = 60.00 lbs.

(7) Moist wt. of +3/4" fraction (sample split for better representation of moisture content) = 15.00 lbs.

(8) Volume of +3/4" fraction = 0.10 cu. ft. (measured)

(9) Volume of -3/4" fraction = (5) - (8) = 0.30 cu. ft.

(10) Moist wt. of -3/4" fraction = (6) - (7) = 45.00 lbs.

(11) % Moisture of -3/4" fraction = 15.00% (from 500 gr. sample)

(12) Dry wt. of -3/4" fraction = $\left[(10) \div \left(1 + \frac{(11)}{100}\right)\right]$ = 39.13 lbs.

(13) Wt. dry of +3/4" fraction (Entire +3/4" fraction dried due to variance in rock) = 13.55 lbs.

(14) Total dry wt. mass = (12) + (13) = 52.68 lbs.

(15) γ_d mass = (14) ÷ (5) = 131.7 lbs./ft.^{3}

(16) % Moisture mass = $\left[[(6)-(14)] \div (14)\right] \times 100$ = 13.9%

(17) % of +3/4" material = (13) ÷ (14) x 100 = 25.7%

C. Embankment material has 35%-60% rock with maximum size of 6 inches. Rock consists of hard granite and gneiss. Specifications call for compaction control on the mass.

<u>Volume Determinations - 30" Template & Plastic Sheet</u>

(1) Wt. of water to fill template before excavation = 62.40 lbs.

(2) Wt. of water to fill template after excavation = 187.20 lbs.

(3) Net wt. water for excavation = (2) - (1) = 124.80 lbs.

(4) Vol. of excavated material = [(3) ÷ 62.4] = 2.00 cu. ft.

<u>Moisture-Density Determinations</u>

(5) Total moist wt. material excavated = 303.0 lbs. (Material separated on 1" sieve for moisture determination)

(6) Moist wt. of +1" fraction = 116.50 lbs.

(7) Moist wt. of -1" fraction = (5)-(6) = 186.50 lbs.

(8) Moist wt. of portion of +1" fraction (sample can be split due to uniformity of rock) = 10.00 lbs.

(9) Dry wt. of portion of +1" fraction = 9.61 lbs.

(10) % Moisture of +1" fraction =

$$\left[[(8) - (9)] \div (9)\right] \times 100 \qquad = 4.05\%$$

(11) Dry wt. of total +1" fraction =

$$\left[(6) \div \left(1 + \frac{(10)}{100}\right)\right] \qquad = 111.96 \text{ lbs.}$$

(12) Moist wt. of portion of -1" fraction (sample split) = 5.52 lbs.

(13) Dry wt. of portion of -1" fraction = 5.16 lbs.

(14) % Moisture of -1" fraction =

$$[(12) - (13)] \div (13) \times 100 \qquad = 7.00\%$$

(15) Dry wt. of total -1" fraction =

$$\left[(7) \div \left(1 + \frac{(14)}{100}\right)\right] \qquad = 174.30 \text{ lbs.}$$

(16) Total dry wt. = (11) + (15) = 286.26 lbs.

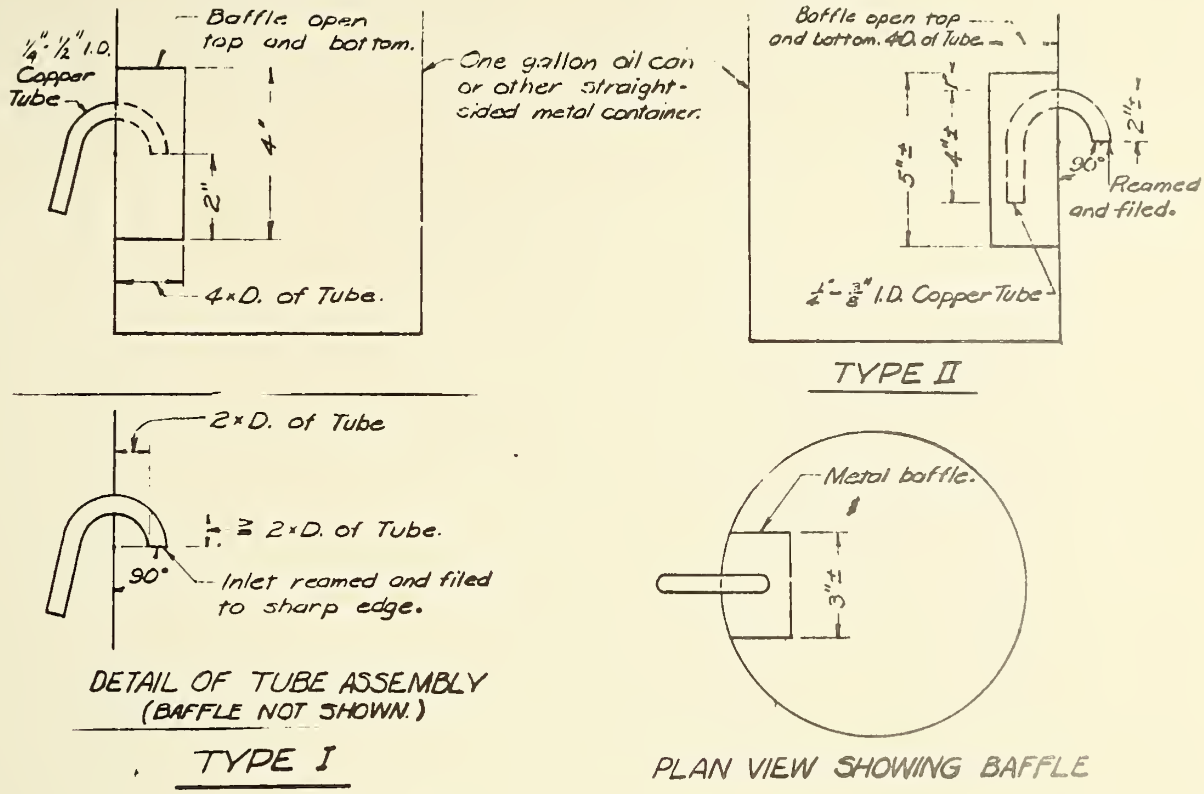
(17) γ_d mass (total) = (16) ÷ (4) = 143.1 lbs./ft.^{3}

(18) % Moisture of mass =

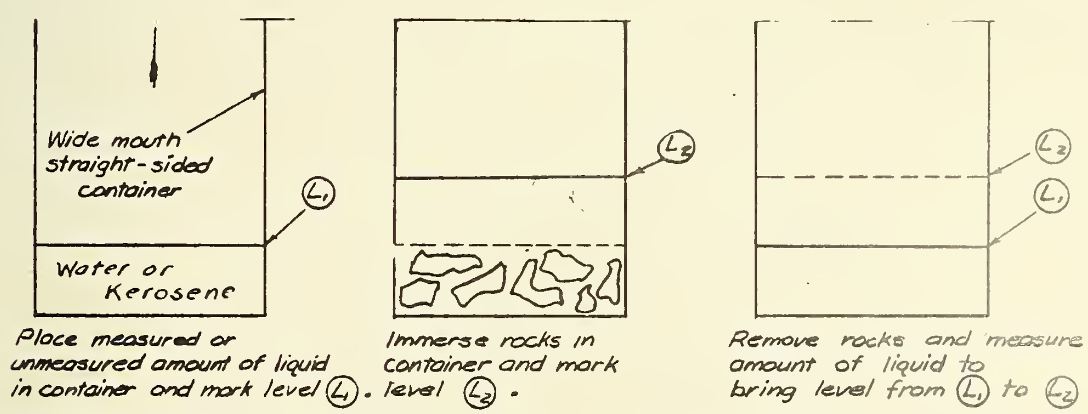
$$\left[[(5) - (16)] \div (16)\right] \times 100 \qquad = 5.9\%$$

Table A-I - In-Place Density Test Specifications

Soil Group	% Rock (+ No. 4)	Maximum Particle Size in Mass Diameter	Compaction Control	In-Place Density Tests				
				Method	Test Hole Volume Cu. Ft.	Test Hole Dimensions		
						Top In.	Bottom In.	Depth In.
IA IIA	< 35	2"	- No. 4	6½" sand cone	0.10	6.5	4	8
		2" - 4"	- No. 4	12" sand cone	0.40	12	8	12
IB IIB	35 - 65	2"	Group IB generally controlled on -3/4" or mass	6½" sand cone	0.10	6.5	4	8
		2" - 4"		12" sand cone 12" template & plastic liner	0.40	12	8	12
		4" - 6"	Group IIB generally controlled on mass	24" to 30" template with plastic liner	1.00 to 2.00	24 to 30	12 to 18	12
		6" - 12"		48" template w/ plastic liner	10.00 to 14.00	48	24	18
IC IIC	> 65	4"	Mass & Method	12" sand cone 12" template w/ plastic liner	0.20 to 0.40	12	Variable	12
		6"	Mass & Method	30" template w/ plastic liner	1.00 to 2.00	30	Variable	12
		12"	Mass & Method	48" template w/ plastic liner	10.00 to 14.00	48	Variable	18
		15"	Mass & Method	72" template w/ plastic liner	15.0 to 18.0	72	Variable	18
III	5 - 65	Indeterminate	Mass	6½" sand cone	0.10	6.5	4	8



a. SIPHON CAN FOR MEASUREMENT OF VOLUME BY DISPLACEMENT.



NOTE: If initial amount of liquid is measured into container as V_1, only the final level, L_2, need be marked; then volume of solids V_s = VOLUME REQUIRED TO FILL TO LEVEL L_2 MINUS V_1.

b. MEASUREMENT OF DISPLACEMENT IN UN-GRADUATED CYLINDER.

FIGURE A-1: METHODS OF MEASURING VOLUME OF SOLIDS BY WATER DISPLACEMENT.